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Henke, D ; Barmettler, A ; Meier, E

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# BISTATIC EXPERIMENT WITH THE UWB-CARABAS SENSOR - FIRST RESULTS AND PROSPECTS OF FUTURE APPLICATIONS

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## ABSTRACT

Bistatic SAR experiments are in focus in recent years. We will present first results of an airborne bistatic experiment conducted 2007 in Switzerland with the Swedish ultra-wideband sensor CARABAS, operating at 28-73 MHz (UWB). The acquired bistatic data include HH and HV polarization with different bistatic elevation angles, various transmitting flight tracks – including non-linear tracks – and fixed receiving antennas (horizontal and vertical) installed on a mountain top. We will place an emphasis on the processing, improving and evaluating of the data and give an overview of future applications which are made feasible by this bistatic dataset.

**Index Terms**— bistatic, UWB, TDBP, dual-pol

## 1. INTRODUCTION

Bistatic SAR is a promising new SAR technology which on the one hand demands increasing requirements on the processing of the data, but on the other hand provides an opportunity for a range of new interesting applications.

Thus, we will first describe the experiment and place an emphasis on the challenges that are associated with the processing of bistatic data with an arbitrary transmitting flight track while the receiving antenna is fixed. We use a time-domain backprojection (TDBP) algorithm to deal with the problem of non-linear configurations. Furthermore, a sub-aperture based method is used to improve the quality of the processed images by introducing a contrast measurement for each single sub-aperture. Due to bad resolution caused by inappropriate geometry (e.g. during a circular bistatic flight) and impreciseness in the flight track data some sub-apertures are discarded automatically by an edge detection filter as a measurement of contrast. Finally, the quality of the obtained results is evaluated.

Following, applications that become feasible by this unique dual-pol, multistatic UWB dataset are presented. We will give an overview of concepts and ongoing research activities at the Remote Sensing Laboratories (RSL), including improving signal-to-clutter ratio of artificial

objects in forested areas, 3D-SAR, detecting forest areas in dual-pol data and tracking of moving targets.

## 2. BISTATIC SAR DATA PROCESSING

### 2.1. Bistatic CARABAS experiment test site

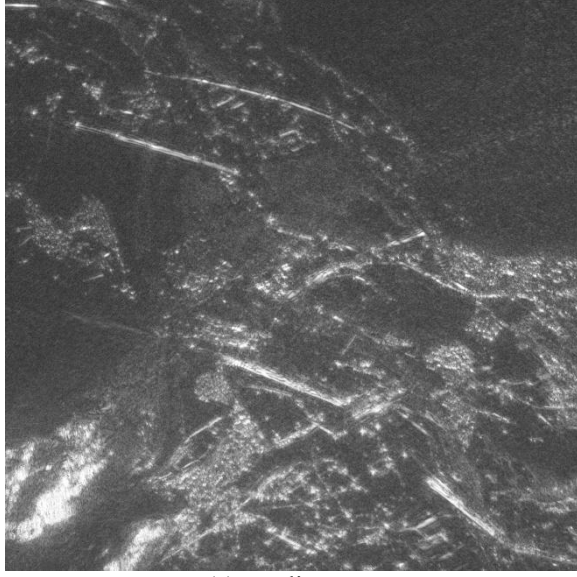
The bistatic experiment was conducted in September 2007 in Spiez, Bern, Switzerland with the CARABAS-II/LORA-system (see table 1) of the Swedish Defence Research Agency (FOI). The receiving antennas (LORA as stationary receiver) were placed on a mountain top (Mount Niesen, 2362m a.s.l.) with horizontal and vertical orientation. The CARABAS-II transmitter installed on an aircraft illuminated the test site (~620m a.s.l.) on the foot of the steep Mount Niesen for several linear and circular flight tracks with different altitudes (ranging from about 3700m-5600m a.s.l.). More comprehensive information on campaign planning and realization can be found in [1].

CARABAS-II/LORA	
Center frequency	50 MHz
Chirp bandwidth	45 MHz
Stepped frequency chirp	CARABAS-II: 23 bands (~2MHz) LORA: 4 bands (~11MHz)
PRF	130 Hz
Ground speed	~100 m/s
Azimuth beam width	> 90°

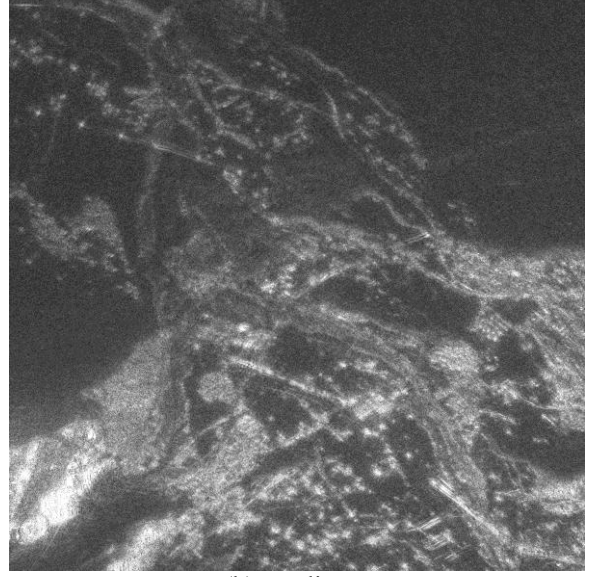
**Table 1.** CARABAS-II/LORA system specifications.

### 2.2. TDBP processing of linear and non-linear bistatic data

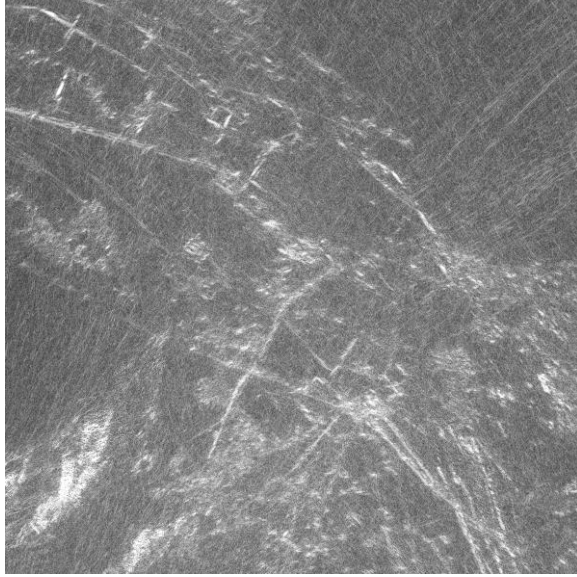
In [1, 2] first results only for an HH linear bistatic case were presented. To deal also with non-linearity the TDBP algorithm is an appropriate choice as was shown in [3] for the non-linear monostatic case. Furthermore, we use sub-aperture processing to be able to analyze the contrast of each single sub-aperture and hence, to implement an automatic filtering of noisy and insufficient parts of the synthetic aperture governed by the contrast measurement.



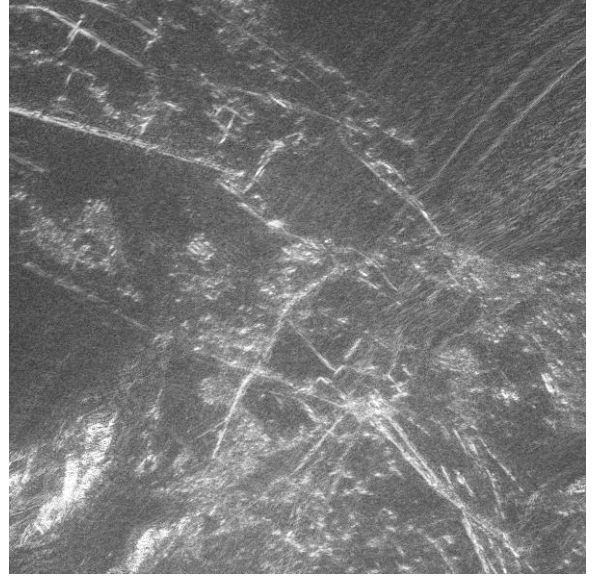
(a) HH linear



(b) HV linear



(c) HH circular



(d) HH circular with automatic sub-aperture filtering



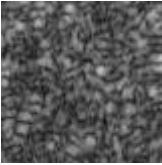

**Figure 1.** Bistatic processing examples for HH and HV linear transmitting flights (top) and HH circular flight before and after contrast based filtering (bottom).

The results of the TDBP processor are illustrated in figure 1 (a)-(c). For the circular flight track 1(c) the image quality of the standard output can still be improved since using the full synthetic aperture might not be a wise choice. Parts of the aperture show degraded quality due to inappropriate acquisition geometry in some segments of the circle and partly also due to slightly imprecise flight track data which leads to a downgrade of the quality of the whole image. Therefore, we process the track in multiple sub-apertures and use an edge detection filter to determine the contrast of each single segment of the circle. As appropriate

choice for the edge detection filter, we apply a filter proposed by Macleod in [4], which is defined as followed:

$$f(m, n) = e^{-\frac{m^2+n^2}{d_r^2}} \left[ e^{-\left(\frac{d_{mn}+d_{pk}}{d_{pk}}\right)^2} - e^{-\left(\frac{d_{mn}-d_{pk}}{d_{pk}}\right)^2} \right]$$

with  $m$ ,  $n$  being the local filter coordinates,  $d_r$  the local expansion,  $d_{pk}$  the distance from the maxima to the origin and  $d_{mn}$  the orientation of the operator. We use the absolute value of the sum of all pixels after edge filtering with vertical and horizontal orientation as measurement of the

	0° bistatic angle (mono)	20° bistatic angle
Vehicle		
Forest (Trees)		
Signal-to-Clutter	6 dB	13 dB

**Table 2.** Signal-to-Clutter Ratio.

contrast for each sub-aperture. By applying this method to all segments of the circle (or an arbitrary flight track in general) the segments which show a contrast below a certain threshold (in our case the mean minus the standard deviation of all segments) are discarded and thus the image quality of the SLC can be improved significantly as figure 1(c) (full aperture) and (d) (after filtering) points out.

Additionally, an analysis of the image quality was conducted with the help of corner reflectors which were placed on open fields during the campaign; parameters like resolution and noise were derived. Unfortunately, during the campaign interferences with local broadcasting frequencies occurred and thus, some frequency bands were corrupted and had to be discarded. Having this reduction in bandwidth in mind, the resolution of the bistatic SLCs (radius of corner reflector  $\sim 2.2\text{m}$ ) is close to the theoretical maximum. Furthermore, the analysis clarifies the potential of the proposed contrast based method for the bistatic circular flight track since the signal-to-noise ratio could be significantly improved by more than 4 dB (from 10.2 dB to 14.4 dB, even though the number of processed echoes is reduced).

### 3. OVERVIEW OF APPLICATIONS

By successfully processing the data a range of applications of the bistatic dataset arises. One that has already been discussed in [2] is the reduction of clutter for the detection of artificial objects (e.g. vehicles) in a forest. Trees which generate a strong signal return in monostatic images due to the double-bounce effect disappear with increasing bistatic angle. On the other hand the backscattered signal response of artificial objects like vehicles is by far not as dependent from the bistatic angle (see table 2). Therefore the signal-to-clutter ratio for vehicles in forested areas can be improved significantly and thus, a more robust detection of objects can be guaranteed as e.g. needed in change detection applications for identifying moving objects in two subsequent SAR scenes.

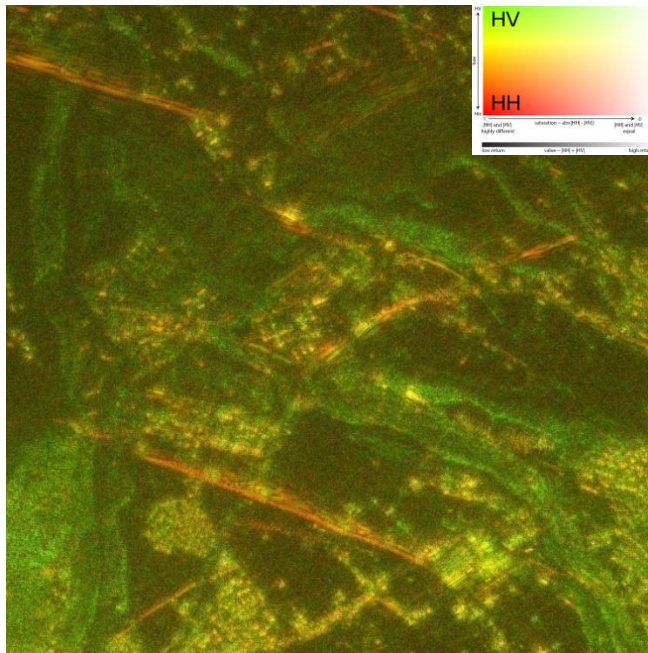
Another potential application is the processing of 3D SAR data. An algorithm to calculate height profiles from several CARABAS monostatic flight tracks was implemented at RSL. We use the advantage of the huge

azimuth beam width of more than  $90^\circ$  to be able to generate a height model from non-parallel, almost arbitrary flight tracks, e.g. for glaciers (the low-frequency of CARABAS allows penetration into dry ice up to a certain depth). An interesting application for future campaigns is the evaluation of this method for deriving glacier properties by using bi-/multistatic data with the advantage of simultaneous data acquisition and lower costs compared to multiple monostatic flights.

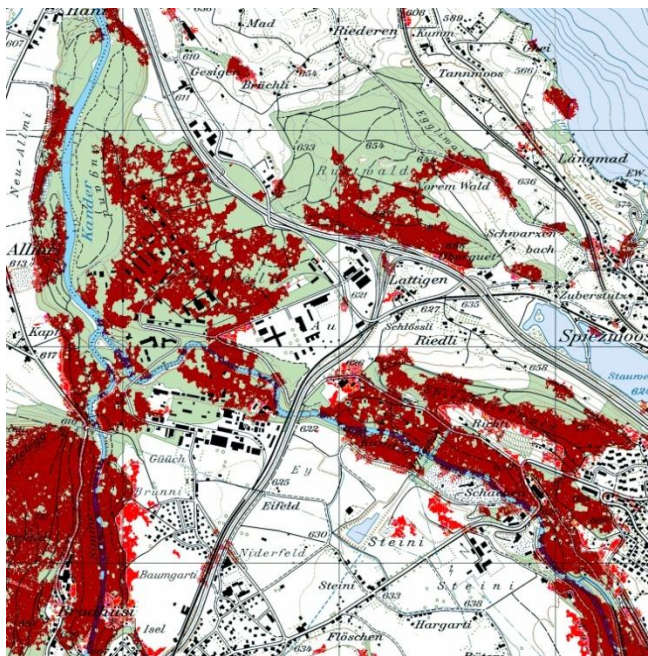
The dual-pol data which are recorded with horizontal and vertical receiving antennas installed on Mount Niesen are an additional feature of the bistatic experiment. For low-frequency SAR systems dual-pol data are quite unique and can only be recorded in a bistatic configuration with fixed antennas because of the requirements in antenna length and the associated problem of installing it vertically on an airplane. Polarized data are investigated at RSL and are useful in characterizing and classifying forested areas. In figure 3 a HH/HV false color composite image is illustrated and a basic algorithm is used to detect forested areas at a  $3 \times 3 \text{ km}^2$  test site on the foot of Mount Niesen. The approach used here is based on least square Support-Vector-Machines (LS-SVM) [5] and a region-growing filter algorithm with automatically selected seed points, known as morphologic reconstruction [6] which is defined by recursive morphological dilatation. It mainly is meant to illustrate the potential of multistatic, dual-pol data in the context of forest classification with low-frequency SAR data and to show first results. We use for each bistatic elevation angle ( $4^\circ$ ,  $10^\circ$ ,  $20^\circ$ ) the HH and HV channels (which are a kind of BRDF approximation) as input features for the SVM and train it with 3% of the labeled pixels. A modified SVM gives in addition to the class affiliation an approximated probability, which is then used as input for the morphologic reconstruction. Alternatively, as an unsupervised solution the HV-to-HH ratio can be used as input for the morphologic reconstruction. Final results are illustrated in figure 3(b). For future applications terrain dependent corrections have to be made (in figure 3(b) one can see that e.g. in “Rustwald” the classification fails in the northern part of the forest due to the topography of this area) and more sophisticated classification methods may be needed to guarantee more robust results. Nevertheless, the potential of dual-pol UWB SAR data for detecting and characterizing forested areas becomes evident.

Furthermore, the dataset allows experiments with bistatic moving target identification which is part of ongoing research at RSL. Static targets focus on the same point on the ground in mono- and bistatic images while moving targets are smeared and centered on different positions on the ground. This dependency is investigated and promising for the identification of moving objects.





(a) HH/HV composite for 3x3 km<sup>2</sup> area



(b) Map overlaid by forest detection algorithm (red)  
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**Figure 3.** Forest detection using the dual-pol bistatic dataset.

## 4. CONCLUSION

Bistatic, dual-pol low-frequency SAR data were processed and presented for linear and non-linear transmitting flight tracks. To deal with acquisition geometry restrictions caused by the non-linearity a method for improving the image quality was introduced and evaluated.

Moreover, we presented concepts and first outcomes of applications resulting from this dataset. Among other things we could demonstrate the potential of different bistatic elevation angles to improve the signal-to-clutter ratio of vehicles and the potential of dual-pol data to detect forest areas with low-frequency UWB SAR systems. Additionally, ideas of future applications which become feasible by this unique bistatic dataset were pointed out and are part of ongoing research at RSL.

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